Machine Learning from Cosmological Simulations to Identify Distant Galaxy Mergers

arxiv.org/abs/1809.02136

What is the role of mergers in galaxy evolution?

agreement last 10 Gyr:
Lin+ 04
Conselice+ 08,09
Hopkins+ 09,10
Bluck+ 11
Lotz+ 11
Snyder+ 11
Man+ 2012

untested! massive galaxies form here

LCDM predicts rising rates

e.g. Rodriguez-Gomez et al. 2015

Galaxy Merger Rate

time= 0   8   12 Gyr ago
redshift= 0   1   2 3 4 5 6

See Also

Illustris Synthetic Deep Fields
https://archive.stsci.edu/prepds/illustris/

SST simulation
IRAC 1
IRAC 2
IRAC 3

JWST simulation
F356W
F444W
F560W

HST XDF   FIELD A
FIELD B   FIELD C

JWST/CEERS Mocks (Coming Soon)

High-Res Mocks (w/ Marc Postman, Jason Tumlinson)

"HST Ultra Deep Field"
2.4 m
S/N=5 @ J=29.4

"LUVOIR-B"
8 m
S/N=5 @ J=31.2

"LUVOIR A"
15 m
S/N=5 @ J=33.9

"ELT"
39 m
S/N=5 @ J=31.9

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Ask me about:
‣ Galaxy Evolution
‣ STScI, MAST
  ‣ Postdoc Program
  ‣ High Level Science Products
  ‣ Digital Object Identifiers

STScI

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Input Labels

Mergers identified in Illustris Simulation:
‣ 10:1 mass ratio (Rodriguez-Gomez+15)
‣ final merger in +/- 250 Myr

mergers:

non-mergers:

Dataset & Features

‣ 10^6 mock HST & JWST images, mainly z > 1
‣ Common non-parametric morphology stats
‣ illustris-project.org/data

The Illustris Simulation
M. Vogelsberger, S. Genel, V. Springel, P. Torrey, D. Sijacki, D. Xu, G. Snyder, S. Bird, D. Nelson, L. Hernquist

Optical
X-Ray
SZ-y
Annihilation
Dark Matter Density
Metal

Validation

‣ We trained 10-d random forests (RFs) using five morphology statistics from each of I and H mock images.
‣ RFs beat individual morphology stats
‣ All manual encoding methods we tried had poor purity (30-50%) in Illustris.
‣ Sims might be saying this is harder than we thought—motivates auto-encoding methods e.g. Deep Learning

Perfect Classifier
RFs
classical techniques
Completeness
False Positive Rate

$\log_{10} n_{merger}$ merger proportion $\log_{10}(P_{RF} \geq th_{best})$
ACS-F814W   z = 1.5
G
M20

Results

‣ Apply trained RFs to CANDELS
‣ RFs pick bulges in post-mergers, asymmetries in pre-mergers
‣ Find rising merger rate, similar to Snyder+17 pair timescales
‣ Estimate 2X too many mergers
‣ Possibly from imperfect morphology distro. via feedback physics
‣ May require Transfer Learning & better sims to improve

"bulges"
"disturbances"
Importance for past mergers
Importance for future mergers

$S(G, M_{20})_I$ $S(G, M_{20})_H$
$F(G, M_{20})_I$ $F(G, M_{20})_H$
A_I A_H
D_I D_H
C_I C_H

RFs applied to CANDELS
theory
pair statistics
galaxy merger rate [Gyr^{-1}]
redshift

Summary

1. We mock-observed Illustris in popular HST & JWST filters, and measured common non-parametric morphology statistics (Lotz+04, Freeman+13).

2. Using this manual encoding, we trained 10-d random forests on simulated mergers with a broad definition of 10:1 mass ratio within +/- 250 Myr.

3. The RFs achieve superior completeness by leveraging different features in pre-mergers versus post-mergers.

4. We recover the expected rise in merger rates versus z, matching earlier merger stages (pairs).

5. IllustrisTNG public on 12/7/2018, and CNN studies in progress, stay tuned!

References

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‣ Genel et al. (2014)
‣ Grogin et al. (2011)
‣ Huertas-Company et al. (2018)
‣ Koekemoer et al. (2011)
‣ Lotz et al. (2004)
‣ Pillepich et al. (2018)
‣ Peth et al. (2016)
‣ Rodriguez-Gomez et al. (2015)
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‣ Snyder et al. (2015ab)
‣ Snyder et al. (2017,2018)
‣ Torrey et al. (2015)
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